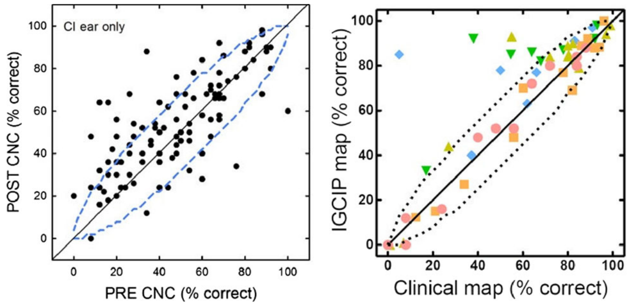

Fig. 2 IGCIP results. *Left panel* results for word scores for 101 adult cochlear implant recipients on consonant-noun-consonant (CNC) word scores with pre scores on the x-axis and post scores on the y-axis. Data points above the diagonal line represent improvement and those outside the dotted banana statistically-significant changes. *Right panel* results for 11 pediatric cochlear implant recipients with *red circles* representing monosyllabic word understanding, the orange squares representing phonemes (unit of sound in a word), and the other symbols representing Baby Bio sentence testing in quiet (*up triangle*) and increasing levels of background noise (*down triangle* and *diamond*)

Conclusions

We have developed a process to utilize post-operative imaging of CI recipients to improve their audiological outcomes by deactivating select electrodes to create independent stimulation channels based on the final post-operative location of the electrode array in reference to the neural endings located in the modiolus. This has resulted in significant improvement in audiological performance with minimal risk to participants consisting of radiation exposure from a post-operative CT scan. For some individuals, this process does not lead to improvement. To study why this occurs, in contrast with previous publications of our approach where at most results with 68 subjects are reported, our now expanded dataset permits studying the relationship between IGCIP benefit and other factors such as demographics and electrode placement. Discovering these key factors is an important step towards improving our approach and/or predicting which subjects will likely receive benefit.

Surgical planning tool for bonebridge implantation using topographic bone thickness maps

M.M. Barakchieva[1], W. Wimmer[1], P. Dubach[2], A. Arnold[2], M. Caversaccio[2], N. Gerber[1]
[1]ARTORG Center for Biomedical Engineering Research, University of Bern, Bern, Switzerland;
[2]Department of Ear, Nose and Throat Diseases (ENT), Head and Neck Surgery, University Hospital of Bern (Inselspital), Bern, Switzerland

Keywords Surgical planning · Bone conduction implant · Bonebridge · Topographic bone thickness map

Purpose

The Bonebridge^{TM} (BB, MED-EL Corporation, Innsbruck, Austria) is a bone conduction hearing implant employed for patients with conductive and mixed hearing loss, as well as single-sided deafness. The large size of its implantable transducer (height 8.7 mm and diameter 15.8 mm) in comparison to the limited size of the implantation site (the temporal bone) introduces the risk of interference with critical anatomical structures such as the sigmoid sinus or the middle fossa dura. Currently, to plan a position and orientation for the implant, surgeons inspect 2D image slices from computed tomography (CT) data sets. Due to the complex variation in bone thickness and the limited area in which the device can be implanted, establishing an optimal or safe implant location can be a challenging task for the surgeon. Several methods and software tools have previously been developed to assist surgeons in planning the position of the BB. In previous work, a topographic bone thickness map (TBTM) was developed and tested for the planning of BB implantation procedures. Despite promising efficacy results, the approach was rendered clinically inapplicable due to the time required to perform a plan (30–70 min) and the technical skills required to create the plan.

Automated segmentation of the temporal bone is challenging as it is highly interspersed with air cells. In some published work a statistical shape model was used to enable a fast and automatic bone segmentation, however, the model excludes malformed anatomy, which limits its clinical applicability. Others proposed methods using thresholding followed by manual correction to generate the temporal bone surfaces. Herein, a planning software tool for BB implantations enabling clinical users to conduct a TBTM plan in less than 15 min on both typical and malformed anatomy is presented.

Methods

The proposed planning software tool for BB was developed using the C++ programming language and is structurally based on a previously developed planning software for cochlear implantation procedures. From a preoperative CT data set, a plan is performed in four primary steps: 3D reconstruction of the bone, TBTM generation and display, implant positioning and patient transfer.

To achieve faster reconstruction of the bone, a volume of interest bounded anteriorly by the external auditory canal, caudally by the mastoid tip, cranially by the skull base, and posteriorly by the sigmoid sinus (or beyond in retrosigmoid applications), is firstly adjusted by the user. Subsequent image processing is performed in the defined volume. In order to facilitate the consecutive segmentation of the bone using thresholding, air cells are removed using a hole filling image filter which uses morphological reconstruction to remove local minima not connected to the boundary of the image. Thresholding is then applied using a manually set threshold prior to island removal and 3D reconstruction using the marching cubes algorithm.

Preceding TBTM generation, the generated model of the bone is divided into inner and outer surfaces semi-automatically. The user defines a cutting trajectory by picking three landmarks: on the temporal line behind the mastoid tip, on the mastoid tip and on the temporal line in front of the mastoid tip. The shortest geodesic path is computed between the three landmarks and defines the cutting path to separate the two surfaces. The distances between the inner and outer surfaces are computed using the closest vertices of both meshes and are colour encoded and mapped to a TBTM.

The position of the Bonebridge transducer is automatically defined as the centre of a region on the bone surface with maximum average depth and minimal average curvature (see Fig. 1). If no minimum thickness is found, an implant position is proposed at the centre of mass of the outer surface. Subsequently, the surgeon can fine-tune the pose of the transducer manually by dragging it within the 3D scene.

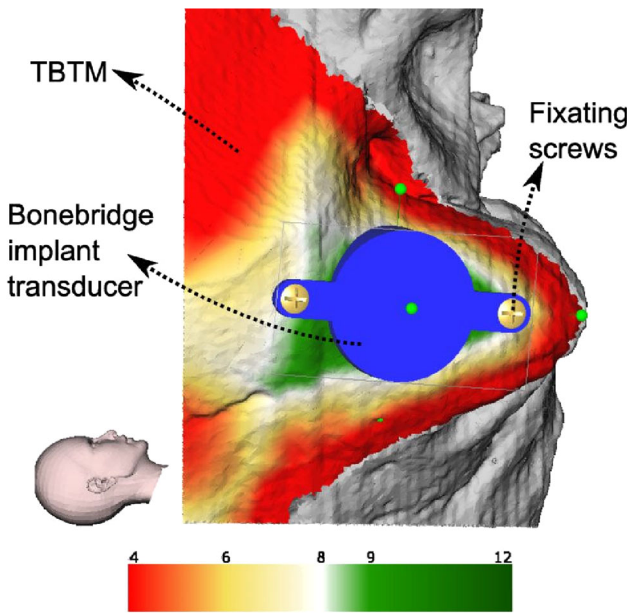

Fig. 1 Position of the Bonebridge transducer

Results

The accuracy of the TBTM generation in the proposed planning software was evaluated on a 3D phantom model of a stepwise wedge (40 mm × 20 mm). To assess the accuracy independent of imaging errors, image data was simulated by exporting a CAD model of the phantom in DICOM format. Additionally, the accuracy of the thickness calculation was evaluated using CBCT images of the rapid prototyped physical phantom (Planmeca 3D, Planmeca, Finland) (V = 96 kVp, I = 12 mA, 0.15 mm isometric resolution). A thickness calculation accuracy of 0.09 ± 0.06 mm was obtained independent of imaging errors (N = 32) and 0.48 ± 0.26 0.48 mm inclusive of imaging error (N = 32).

The feasibility of the approach was validated in the planning of implant positions for five patients from the Inselspital, Bern. The average time of planning was less than 10 min. Surgeon reported that the plan was particularly useful in more challenging cases (e.g. retro-sigmoidal implantation required) (see Fig. 2).

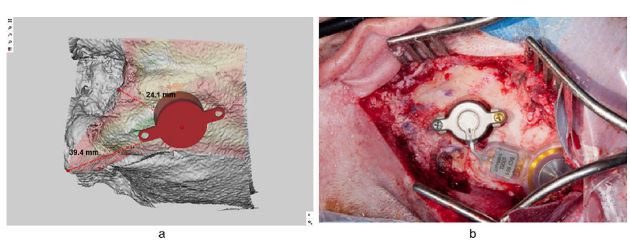

Fig. 2 Surgeon confirm that the planning of implant positions was particularly useful in more challenging cases

Conclusions

Within this work a semi-automatic system for planning a bone conduction hearing implant pose was presented. It provides a fast and semi-automatic segmentation of the temporal bone, using morphological operations to fill in the air cells inside the bone. An optimal implant pose is proposed, which is the centre of the region on the bone with maximal average thickness, minimal average curvature, and size as that of the Bonebridge implant transducer. Intuitive manipulation options for manual fine-tuning of the implant position are presented to the user. Finally, a tool for measuring the distance between anatomical landmarks is provided in order to facilitate the transfer of the plan to the operating room.

Predicting detailed inner ear anatomy from pre-operational CT for cochlear implant surgery

H.M. Kjer[1], S. Vera[2], J. Fagertun[1], F. Peréz[2], J. Herrero[2], M.A. González-Ballester[3], R.R. Paulsen[1]
[1]Technical University of Denmark, Copenhagen, Denmark; [2]Alma Medical Systems, Barcelona, Spain; [3]Universitat Pompeu Fabra, Barcelona, Spain

Keywords Cochlear implants · Image registration · Shape model regularization · CT

Purpose

A Cochlear Implant is a surgically inserted prosthetic device for restoration of hearing given to persons who are profoundly deaf or severely hard of hearing.

Pre- and post-operational CT scans are routinely used in planning and assessment of Cochlear Implant surgeries. However, due to the small size of the implant and cochlea, the images contain only very gross anatomical information about the inner ear.

Providing additional patient-specific anatomical information about the inner ear is very valuable. It allows surgeons and manufacturers to make decisions about the design and programming of the inserted implant, in a manner that optimizes the restored hearing capabilities of the recipient. A promising way of achieving this is to use statistical shape models from high-resolution imaging techniques such as µCT. Previous work already [1] shows the potential and the interesting clinical implications/applications.

In this study we present an alternative image registration approach for predicting detailed inner ear anatomy in pre-operative CTs using Statistical Deformation Model (SDM) regularization. Further, we present some preliminary evaluation of the clinically predictive accuracy.

Methods

The statistical model: A Statistical Deformation Model (SDM) [2] was built from 17 µCT datasets of inner ear cadaverous specimens. One segmented dataset was used as a reference to which the remaining datasets were non-rigidly registered using a B-spline registration model [3]. The high resolution of this type of data allows us to segment finer anatomical details not visible in normal CT.

Segmentation of clinical CT: In order to project the high resolution µCT inner ear model into the clinical CT data we use a series of image registrations (see Fig. 1) following the formulation of the elastix toolbox [4].

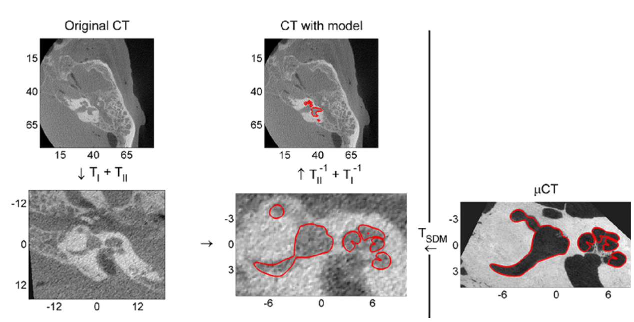

Fig. 1 Illustration of the transforms in the proposed procedure. T_I and T_{II} are rigid transforms bringing data form the CT space (*upper row*) to μCT space (*lower row*) and back. The registratioin between μCT abd CT is regularized with the SDM. Axes units are in mm